THERMODYNAMICAL AND STATISTICAL PROPERTIES OF AN ELECTRON GAS

BY

HUNG SHIH WU

B.S., National Central University, China, 1942
M.S., University of Michigan, 1946

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN ELECTRICAL ENGINEERING
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R. UNIV. BIBLIOTHEEK LEIDEN

THERMODYNAMICAL AND STATISTICAL PROPERTIES OF AN ELECTRON GAS

Electrons in an electron beam always travel with a velocity, consisting of two components. One is due to the exetrnal field, and the other is a random velocity, different for each electron. Under ordinary conditions, the mean square of the random velocity corresponds to a very low voltage, and may be neglected when compared to that due to the external field. The motion of the electrons and the behavior of the electron beam can be strictly solved by electrodynamical method.

However, if one comes to phenomena involving the random velocities of the electrons themselves, like the shot noise occuring in an electron beam, the method of elecctrodynamics will no longer be applicable. Random velocities are related to the inherent kinetic energy and hence the temperature of gas. One must therefore resort to methods of thermodynamics.

It can readily be seen that the particular behavior of an
d essentially by the mutual repelling forces
ıt equally charged particles. These forces
ulomb energy of the electrons, and have to
ıt in the thermodynamic theory of an elec-
of this particular Coulomb energy of elec-
ergy of the electron gas is not a linear
total number of electrons. This non-
of an electron gas makes its thermody-
ıot only a function of the total volume, but
he geometrical configuration of the whole
ing, only the simplest spherical geometry

ynamics can describe a gas only when it is
ıplications arise that owing to the mutual repelling forces among electrons, any concentration of free electrons in a vacuum is always unstable and in continuous expansion, even if no external field is applied. Beams spread,

clouds expand and time seems to offer itself as a new variable in defining the boundaries of any electron gas.

In this thesis, an attempt is made to discard time as an independent variable. One has therefore to consider either a quasi-stable or a completely stable electron gas. An electron gas is defined as quasi-stable within a certain time interval which is too short for the gas to expand appreciably yet which is long enough for electrons inside the gas to complete their interactions to reach equilibrium. It may then be treated in the same manner as a stable electron gas. In such a quasi-stable electron gas, there exists the advantage of an arbitrarily chosen density distribution. On the other hand, by sacrificing this advantage of an arbitrarily chosen density distribution, one can establish a completely stable electron gas. A hollow vessel, coated inside with electron emitting material and heated to a temperature sufficient for thermionic emission of electrons would produce the desired properties.

According to the above considerations the whole thesis is then divided into two different parts.

In the first part of this thesis, a quasi-stable spherical electron gas is analyzed. The primary object is then to find its thermodynamical properties. Since these macroscopic properties of an electron gas are only the collective results of the microscopic behavior of individual electrons, one therefore has to start from a general statistical theory. It is found that the fundamental link between thermodynamics and statistics lies in the so-called Helmholtz free energy. This quantity is evaluated from the general statistical theory of an imperfect gas by taking into consideration the particular behavior of the electrons. From the Helmholtz free energy, one can therefore derive for the electron gas the equation of state, entropy, inner energy, enthalpy, specific heats, velocity of sound, and the Joule-Thompson effect.

In the second part of this thesis, a completely stable spherical electron gas is analyzed. The behavior of electrons within the sphere under equilibrium conditions can be described by

Poisson's equation together with Boltzmann's distribution law. A non-linear differential equation of the potential is derived and solved by a particular method of successive approximations. With this potential function, it is then possible to obtain all other electrical and thermodynamical properties of this electron cloud. Possible application of this spherical cathode as a low voltage high current density electron gun is also discussed.

VITA

The author, Hung Shih Wu, was born June 23, 1922 at Nanking, China. He graduated from the National Central University of China with a B.S. degree in Electrical Engineering in 1942. Since then he was employed as a teaching assistant in charge of communication laboratory at the same university. In 1944, he passed a competitive examination sponsored by the govenment and was sent to the United States in September, 1945 for further radio training. He first attended the University of Michigan and received the degree of M.S.E.E. in June, 1946. During the years 1946-1948, he joined the Special Development Group, RCA Victor Division at Lancaster, Pennsylvania, doing theoretical research on microwave magnetrons and travelling wave tubes. From September 1948 until now, he enrolled at the University of Illinois and was also appointed a half time special research assistant at the Electron Tube Laboratory.

He is an associate member of the Society of Sigma Xi, and also an associate member of the Institute of

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(1) Theoretical Study of Travelling Wave Tube Structures, Technical Report, RCA Victor Division, Lancaster, Pennsylvania, August, 1948.

(2) Electron Bunching Phenomena in a Travelling Field, Technical Report, Electrical Engineering Research Laboratory, Engineering Experimental Station, University of Illinois, March, 1950.

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